



Cosmic Muon Momentum Spectra at Madurai

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- Prototype of ICAL built at Madurai
- Resistive Plate Chamber Properties
- MonteCarlo Simulation
- Momentum Reconstruction
- $\operatorname{Zenith}(\theta)$ and $\operatorname{Azimuth}(\phi)$ distributions.

Prototype of Iron Calorimeter - miniICAL

- In the current prototyping stage, a 1/600 scaled down version is built at Madurai.
- $\bullet~85~{\rm ton},\,4\,{\rm m}\times4\,{\rm m}\times11$ layers of Fe.



- The space between iron plates are populated with Reststive Plate Chambers.
- Aim
 - Performance of Magnet(Max B = 1.5 T by applying 900 A)
 - Performance of RPC over long period
 - Measure Φ(μ⁺), Φ(μ⁻) at Madurai and compare with predictions.

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Resistive Plate Chamber-Properties

- Bulk resistivity of the glass used $3 \times 10^{12} \Omega$ cm.
- Surface resistivity of the graphite coat 0.6 $1.5 \text{ M}\Omega/\Box$.
- \bullet Applied HV $9.8\,\mathrm{kV}$ to $10.2\,\mathrm{kV}.$
- Gas gap 2 mm.
- Gas flow rate 6 sccm.
- Operated in Avalanche mode with a gas mixture of $C_2H_2F_4$ (95.2%), iso- C_4H_{10} (4.5%), $SF_6(0.3\%)$.
- Width of strips in pick up panel 3 cm.
- Intrinsic time resolution $\sim 0.7\,{\rm ns}$ [1].





MonteCarlo Simulation

- The Monte-Carlo simulation is done in two parts. The extensive air shower has been simulated with CORSIKA(v7.6300) package with the magnetic rigidity cutoff for the location of study.
- The hadron interaction models FLUKA and SIBYLL are respectively used in the lower and higher energy range.
- The primaries are generated with form 10 GeV to 10⁶ GeV with a spectral index of -2.7.
- The zenith and azimuth angle of primary particles are generated uniformly within the range of 0-85° and 0-360° respectively, but are allowed to propagate depending on the rigidity cutoff in different (θ,φ) bins.
- The daughter particles at the earths surface level is extracted and given as input to the detector simulation, which is executed with the help of GEANT4.

Contd.

- The detector simulation is performed with GEANT4, where an identical model of the detector including the building is made.
- The detector properties are incorporated in the simulation during the digitisation, efficiency, resolution, multiplicity, noise, etc.



Detector Efficiencies and Cluster Size

- The RPC's are divided into blocks of 64 × 64, and the multiplicity and inefficiency is determined based on the position within a strip.
- This process is carried out separately for the X and Y axis
- During this process the correlation b/w X and Y is lost.
- The joint distribution of the cluster sizes has to match for a faithful reproduction of data.



Unfolding the fitting error & Multiplicity correlation

• The fitting error on the position in a strip has to be unfolded for simulation.



• The multiplicity correlation is incorporated in the

simulation with clayton copula.



Noise Simulation

• The noise in data is separated from the valid muon hits, and reintroduced in simulation.



• The number of layers in fit for data and simulation better matched after including the noise in the simulation



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- The momentum from the bending in the magnetic field.
- The position resolution and the number of layers, significantly affect the muon momentum resolution and efficiency.
- Since we have only 10 layers, we expect a faithful reconstruction in ~ 1 to $3 \,\text{GeV/c}$ range.
- The momentum reconstruction is done by fitting the track with an extended kalman filter algorithm along with a pattern recognition algorithm for track finding [2].

Momentum Spectra



Response Matrix



Data & MC reconstructed momentum distribution

$\operatorname{Zenith}(\theta)$ and $\operatorname{Azimuth}(\phi)$ distributions.



Zenith Distribution

Azimuth Distribution

Azimuth(ϕ) distribution of μ^+ and μ^-



• Note : The plots are without incorporating charge miss-ID correction and unfolding.

- The detector simulation benchmarking is done with various parameter comparisons like number of degrees of freedom, efficiency, position residue, etc.
- The data and Monte Carlo (MC) match results after reconstruction.
- The process of unfolding the generator-level momentum distribution from the reconstructed distribution is still pending.
- The azimuth distribution of μ^+ and μ^- has to be separated and unfolding has to be done for extracting true azimuth distribution.

Thank You

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- J.M. John et. al., Improving time and position resolutions of RPC detectors using time over threshold information, Journal of Instrumentation **17** (2022) P04020.
- Kolahal Bhattacharyaet. al., Error propagation of the track model and track fitting strategy for the Iron CALorimeter detector in India-based neutrino observatory Computer Physics Communications185 (2014) 3259-3268

Backup Slides

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RPC Efficiencies



Comparison of noise with and without Magnetic Field



Noise Occupancy without Magnetic Field



Noise Occupancy with Magnetic Field